MUD VOLCANOES AS EXPLORATION TARGETS ON MARS.
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Introduction: Tens of thousands of high-albedo mounds occur across the southern part of the Acidalia impact basin on Mars (Fig. 1). These structures have geologic, physical, mineralogic, and morphologic characteristics consistent with an origin from a sedimentary process similar to terrestrial mud volcanism [1]. The potential for mud volcanism in the Northern Plains of Mars has been recognized for some time, with candidate mud volcanoes reported from Utopia, Isidis, northern Borealis, Scandia, and the Chryse-Acidalia region. We have proposed that the profusion of mounds in Acidalia is a consequence of this basin's unique geologic setting as the depocenter for the fine fraction of sediments delivered by the outflow channels from the highlands [2,3].

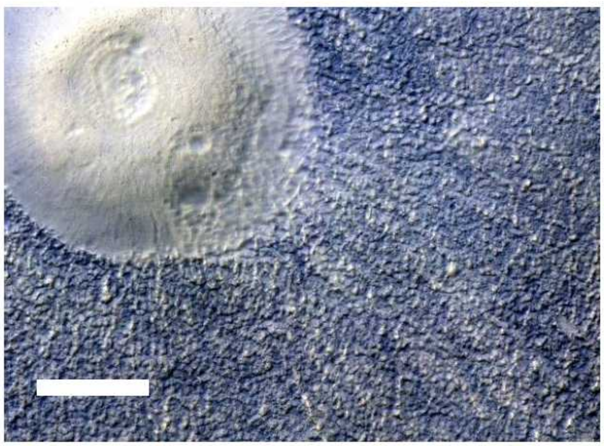

Figure 1. Mud volcano in Acidalia Planitia; HiRISE PSP_002233-2225; 42.1° N, 319.3° E; scale bar 200 m.

Mud volcanoes on Earth: Terrestrial mud volcanoes extrude relatively low temperature slurries of gas, liquid, and rock to the surface from depths of meters to kilometers [4]. These erupting slurries build circular to sub-circular deposits of mud and rock breccia that range in size from meter-scale lumps to mountains. They can produce domes, cones, caldera-like forms, or relatively flat structures. The range of morphologies is thought to reflect physical properties of the rising slurries as well as varying proportions of gas, liquid, and sediment in the extruded materials.

Thousands of mud volcanoes have been identified globally. They have been documented in more than 40 onshore and offshore localities, and are particularly abundant in Azerbaijan and the Caspian Sea [4]. Recent work suggests that tens of thousands may occur on continental slopes and abyssal plains [5].

Figure 2 illustrates one mud volcano from among the hundreds in Azerbaijan. These include large mountainous features with mud flows as well as relatively flat, pedestal-like edifices having high-albedo patches that are remnants of mud lakes [6]. Diameters of the high-albedo patches are generally a few hundred meters; diameters of entire pedestals or mountainous mud volcano systems are commonly one to two kilometers, though diameters of some of the larger mountainous mud volcano systems can approach tens of kilometers, with heights reaching 600 m.

Figure 2. Mud volcano in Azerbaijan with nearly flat, pedestal-like surface and central high-albedo, sub-circular patch; 40.4° N, 49.0° E; scale bar 1 km.

Importance for Astrobiology: Mud volcanoes occur in fluid-rich basins having thick accumulations of rapidly-deposited, fine-grained sediments. Upward mud flow is related to the buoyancy of the muddy and fluid-rich sediments, compared to the surrounding rocks. These settings also are commonly associated with the occurrence of petroleum, as conditions that favor accumulation of rapidly-deposited muds also favor concentration and preservation of organic materials [7]. Because organic materials tend to be deposited with the fine-grained fraction of sediments, organic remnants also can be deposited with muds and fluids in mud volcanoes. Moreover, the abundance of fine-grained sediments can protect any deposited organics from oxidation, thereby enhancing their preservation potential. Such preserved organic materials can include morphological microfossils or chemical degradation products of biomolecules from past life [4].

Mud volcanoes on Earth vent major quantities of gas, mainly methane, produced by thermogenesis at depth. They have been estimated to contribute around 25% of the approximately 40 x 10^6 tons/year of methane released to the atmosphere by all geological sources, which also include macro- and micro-seeps, gas hydrates, magmatic and geothermal sources, and mid-ocean ridges [6,8,9].

Sample analysis: We are studying samples of mud and incorporated breccia from mud volcanoes formed in a range of terrestrial settings. These analyses document the similarities and differences in mineralogy, spectral response, chemical biomarkers, and preserved microfossils.

X-ray diffraction analyses of mud samples from these locations demonstrate that they contain predominantly illite and smectite clays, calcite, and quartz. The visible and near-infrared spectra of all these samples are similar, and are dominated by the signatures of clays (Fig 3).

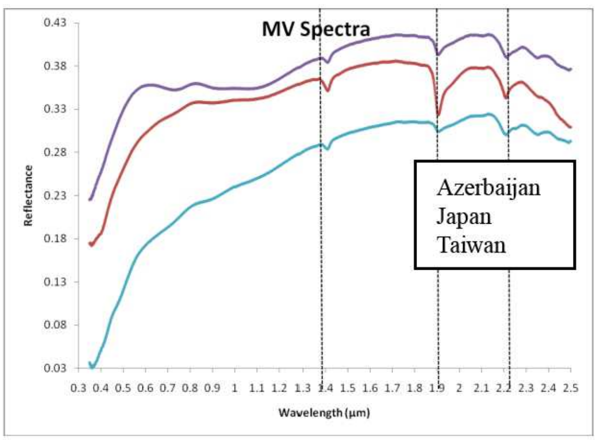

Figure 3. Visible and near-infrared reflectance spectra of air-dried mud sample powders, dominated by the spectral signatures of clays with characteristic water bands.

Chemical biomarkers are present in mud from all three locations. Pyrolysis tests demonstrate that these samples contain between 1.1 and 1.3 wt% of total organic carbon (TOC) and between 0.3 and 0.5 mg of volatile hydrocarbons (to ~C30) per gm of rock. Such TOC values are common in shales with an organic component. The volatile hydrocarbons may represent a mixture of material generated from kerogen in the mud and hydrocarbons that migrated from depth.

Mud and breccia from the Azerbaijan and Taiwan samples contain a variety of microfossils (Fig. 4). These are characterized by calcareous rims and, in some cases, partial fillings of framboidal and non-framboidal pyrite.

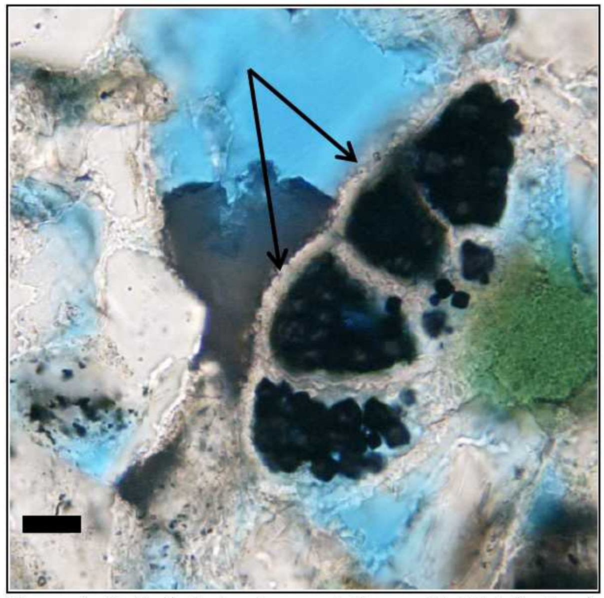

Figure 4. Optical photomicrograph (transmitted light) of rock breccia from the Bozdag mud volcano in Azerbaijan; arrows indicate calcareous microfossil partially filled with pyrite; blue epoxy preparation; scale bar 10 μm.

Exploration targets: Mud volcanism provides a mechanism for transporting sediments from depth to the surface in minimally-altered form. Such sediments could be of astrobiological significance, as they could contain chemical biomarkers, mineral biosignatures, or structural remains from past life deposited from Acidalia's large watershed or from indigenous, endolithic microorganisms (either past or present) that may have survived in porous, fluid-rich microhabitats in the subsurface. The mud volcano-like mounds in Acidalia also could be sites of past and possibly present gas release to the martian atmosphere. Thus we propose that the mounds in Acidalia may offer a new class of exploration target for Mars.

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